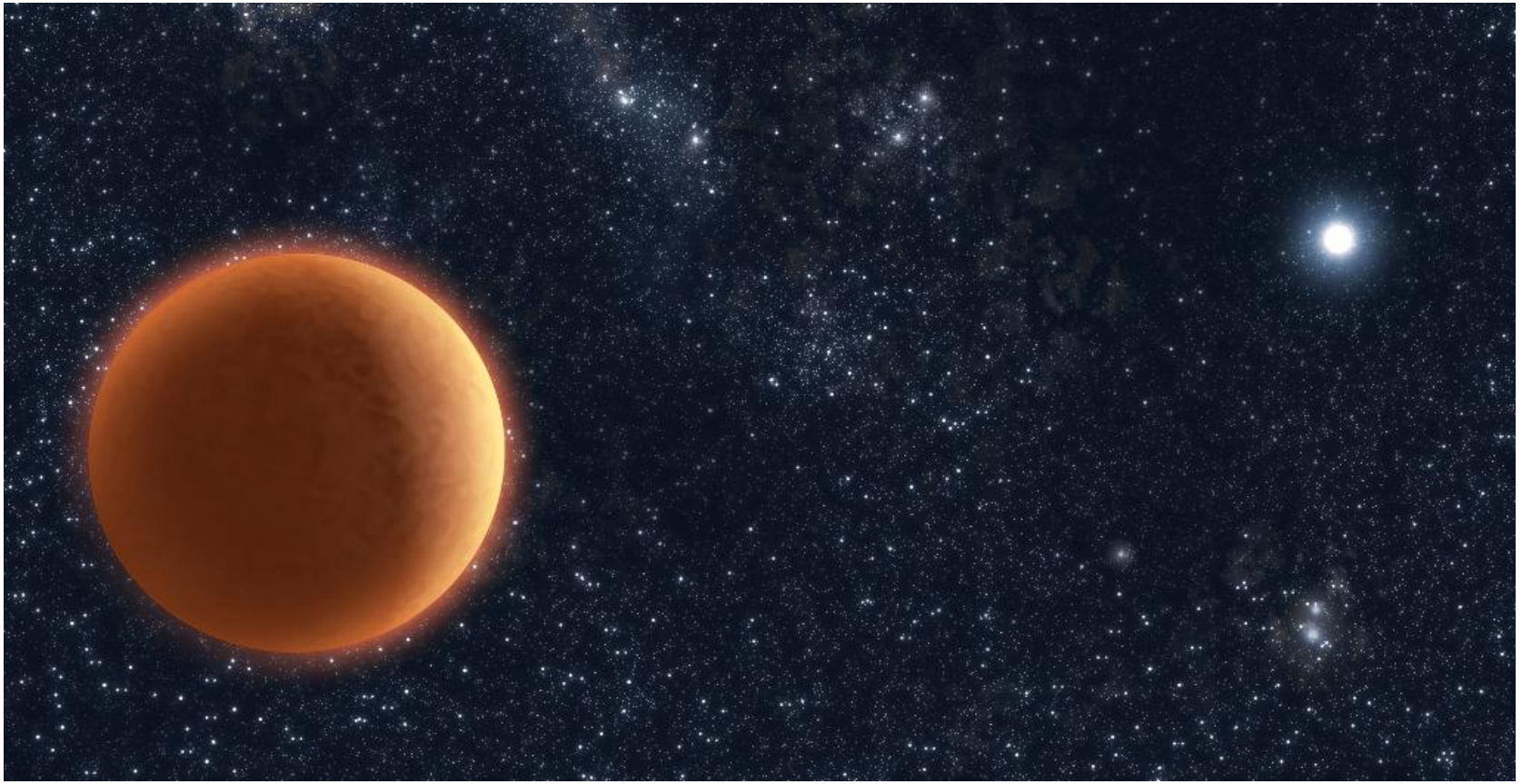


# Planets at White Dwarfs

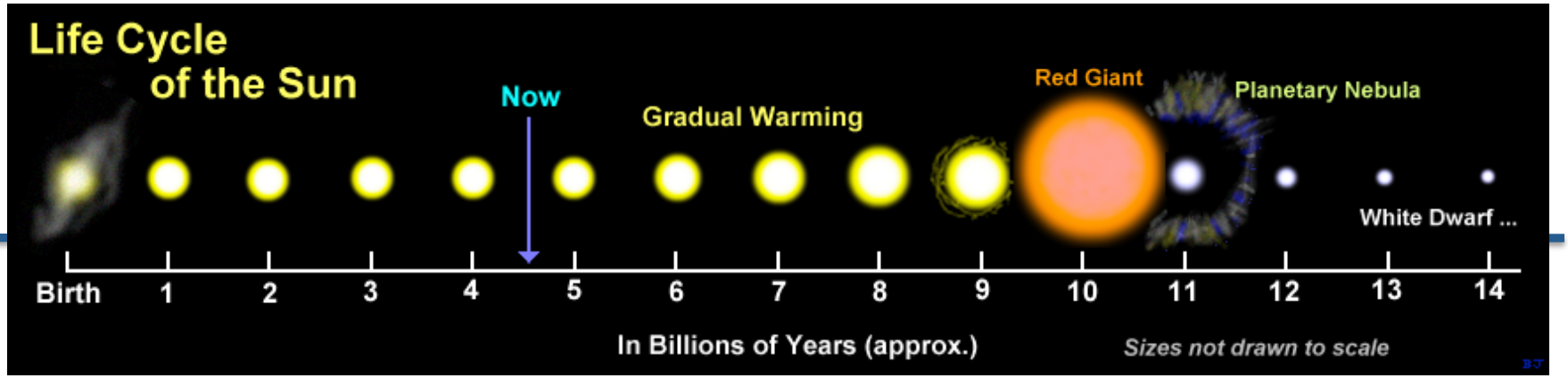
# Or

# *"Cool planets at hot stars"*

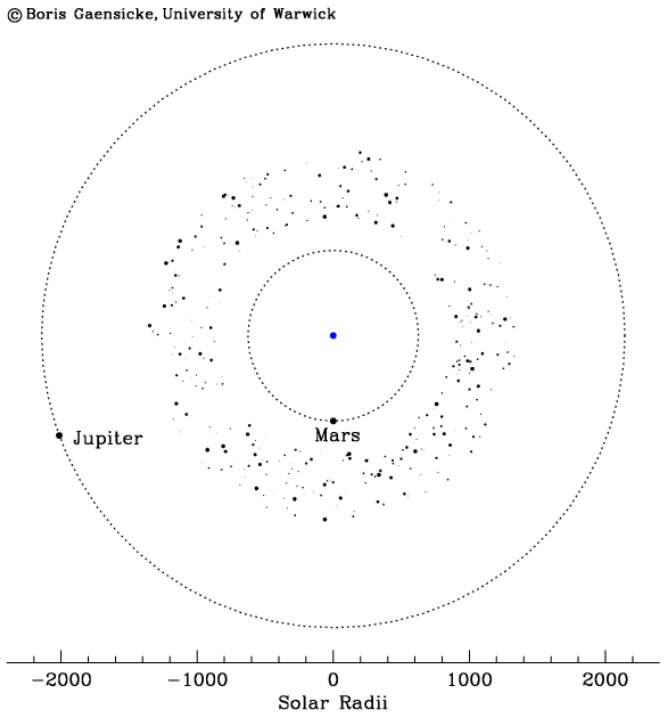
Matt Burleigh

# with thanks to:

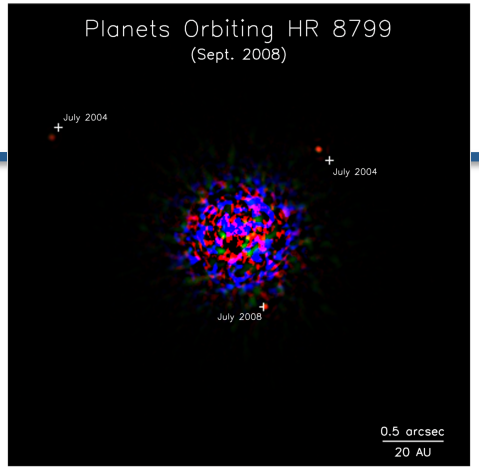

- Sarah Casewell, Martin Barstow, Richard Jameson, Katherine Lawrie, Nathan Dickinson, Melissa McHugh (Leicester)
- Jay Farihi (Cambridge)
- Paul Steele (MPA Garching)
- Paul Dobbie (AAO)
- Francesca Faedi (Warwick)
- Fraser Clarke (Oxford), Emma Hogan (Gemini South), Simon Hodgkin (Cambridge)
- Ted von Hippel, Fergal Mullally (Kepler)
- Avril Day-Jones, Ben Burningham, David Pinfield (Herts)

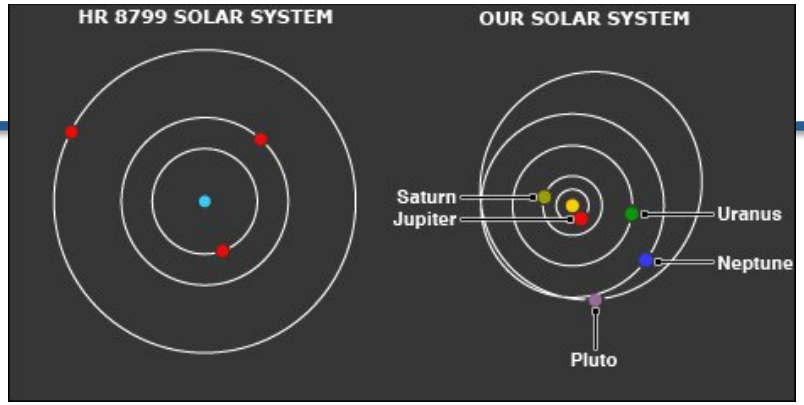



- Burleigh, Clarke & Hodgkin 2002, MNRAS, 331, L41
- Debes & Sigurdsson 2002
- Villaver & Livio 2007, 2009
- Nordhaus et al. 2010
- Veras et al. 2011, 2012
- Debes et al. 2012
- Kratter & Perets 2012
- Nordhaus & Spiegel 2012



# HR8799 as a white dwarf…



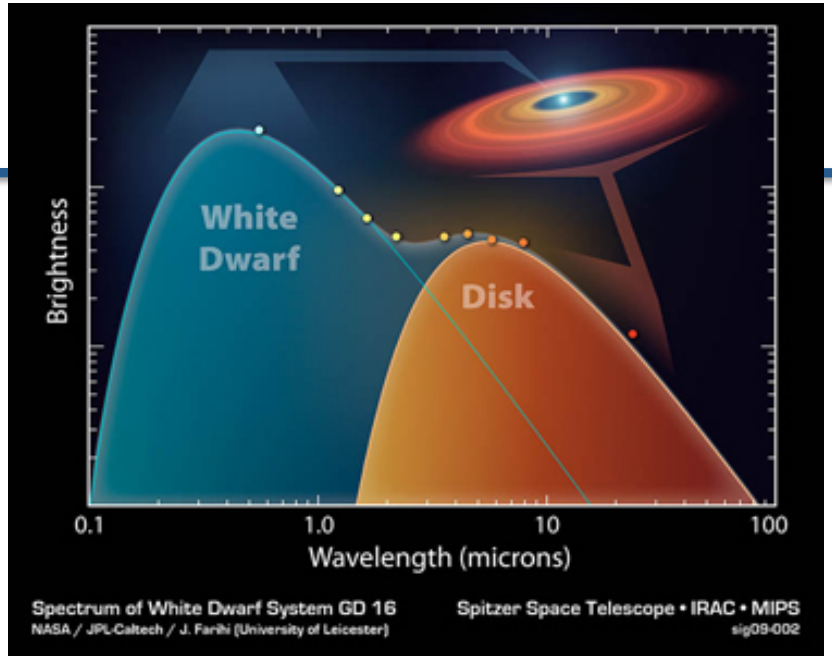



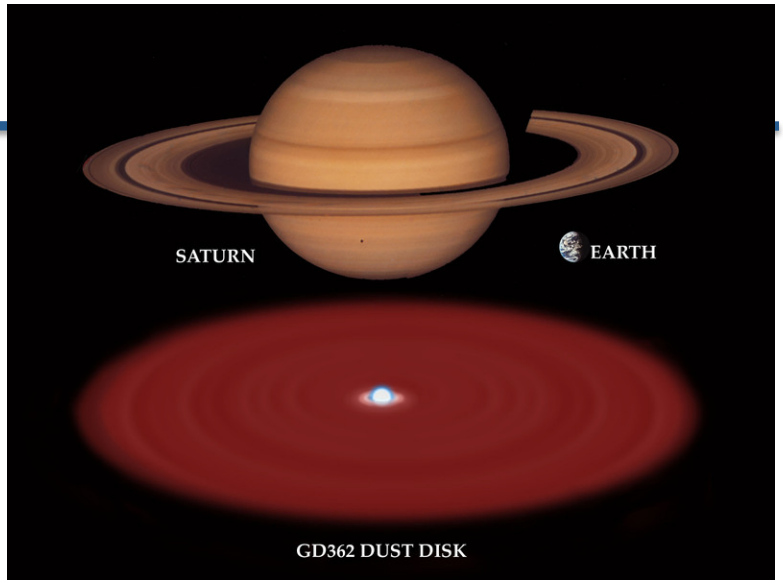

- HR8799: A5V 1.2-1.8$M_{jup}$ 39pc 30-160Myr old
- Planets: 5$M_{jup}$ @ 68AU, 10$M_{jup}$ @ 38AU, 10$M_{jup}$ @ 24AU, 7$M_{Jup}$ @14AU

- Will evolve after 1.75Gyr to a 0.58$M_{sun}$ white dwarf
- Planet orbits expand by factor ~3 to ~200AU,~120AU, 75AU & 45AU

- Let WD cool to 10,000K over ~0.5Gyr….system age now 2.25Gyr…
- 10$M_{jup}$ planet will be J=23.8 @39pc
  - *How common are HR8799-like systems?*

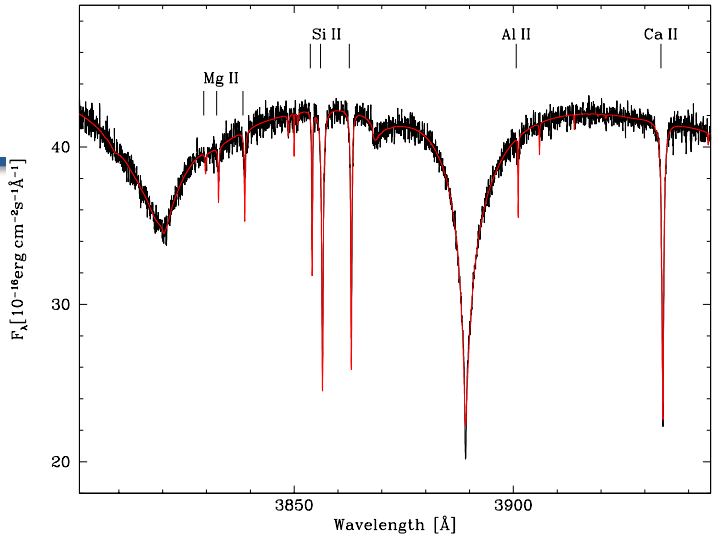
# Dust disks around white dwarfs



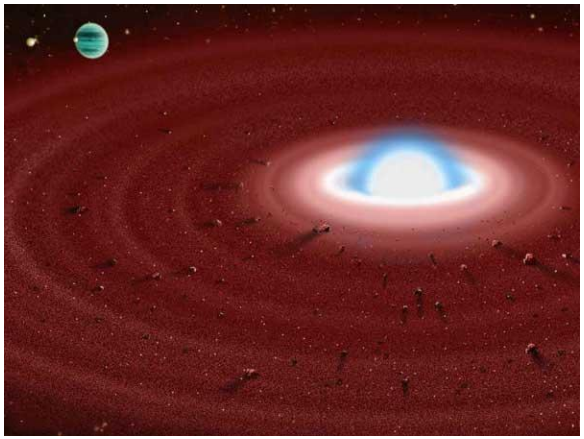




- A dozen WDs are known to be surrounded by dust disks
- Disks identified as near-IR and mid-IR excesses, $500^{o}K < T < 1200^{o}K$
- Disks within a few solar radii of the WDs
- Material within the disks is being accreted onto the WD atmosphere
  - Finally explains WDs with metal-polluted atmospheres

# White dwarfs accrete planetesimals!




- Disks dominated by silicates, atmospheric C/Si & C/O ratios similar to bulk Earth
- Disk forms from tidal disruption asteroid
  - Mass of GD362 disk suggests Mars-sized body
- Suggests at least ~20% of WDs may have rocky companions
  - If all polluted WDs have accreted terrestrial material at some point
- But asteroids have to be moved by something:
  - *Where are the perturbing giant planets?*



# Limits on exoplanet companions to WDs from ground & space

| | UKIDSS (all separations) | DODO (*resolved, >few 10s AUs*) | Spitzer (*unresolved, <few 10s AUs*) |
|---|---|---|---|
| $<75M_{Jup}$ | 0.5+/-0.3% | | |
| $>13M_{Jup}$ | | <5% | <3% |
| $>10M_{Jup}$ | | <7% | <4% |
| $>6M_{Jup}$ | | <1/3 | <12% |

DODO: Hogan et al. 2009, MNRAS, 396, 2074: 28 targets

Spitzer: Farihi et al. 2008, ApJ, 681, 1470 : 34 targets

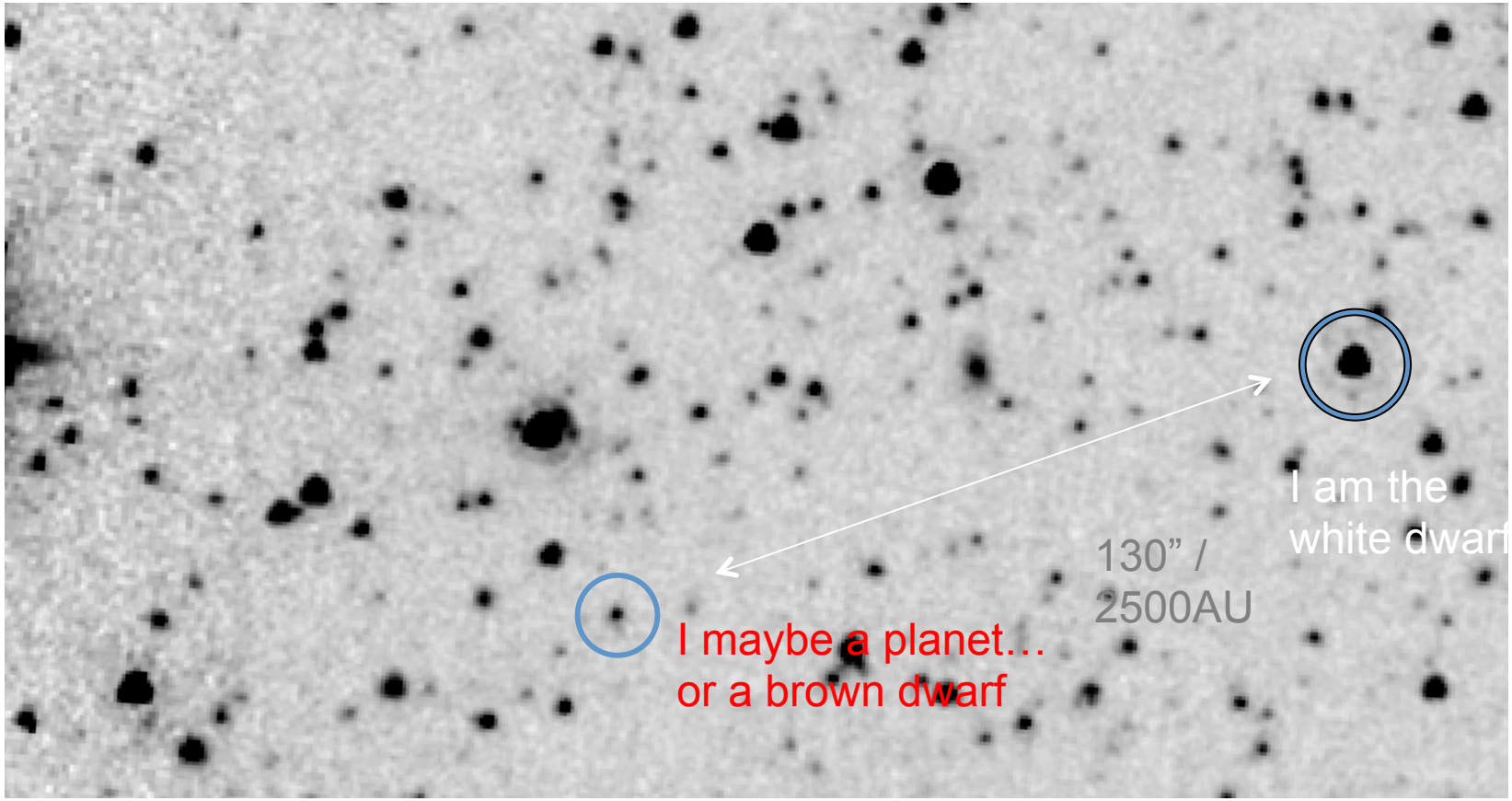
UKIDSS: Steele et al. 2011, Girven et al. 2011: ~1000 WDs

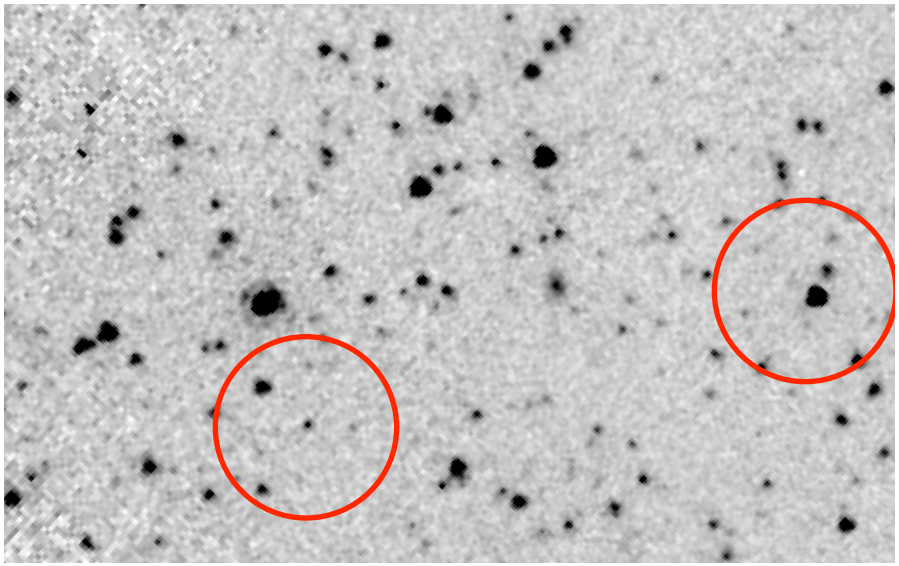
# Spitzer warm mission programme

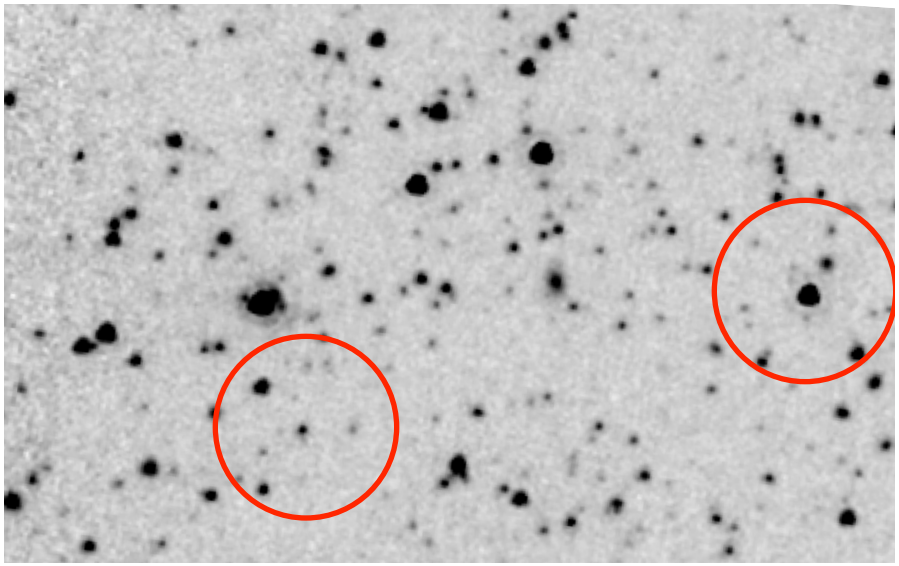
- Repeat observations of ~90 white dwarfs originally observed 2004/5
  - Prog ID: 60161
  - Title: *"Cool, spatially resolved substellar & exoplantary analogues at white dwarfs"*
    - PI: Burleigh, co-Is Farihi, Steele, Mullally, von Hippel
- Look for common proper motion companions
  - 4.5micron band only

# Spitzer 4.5micron image

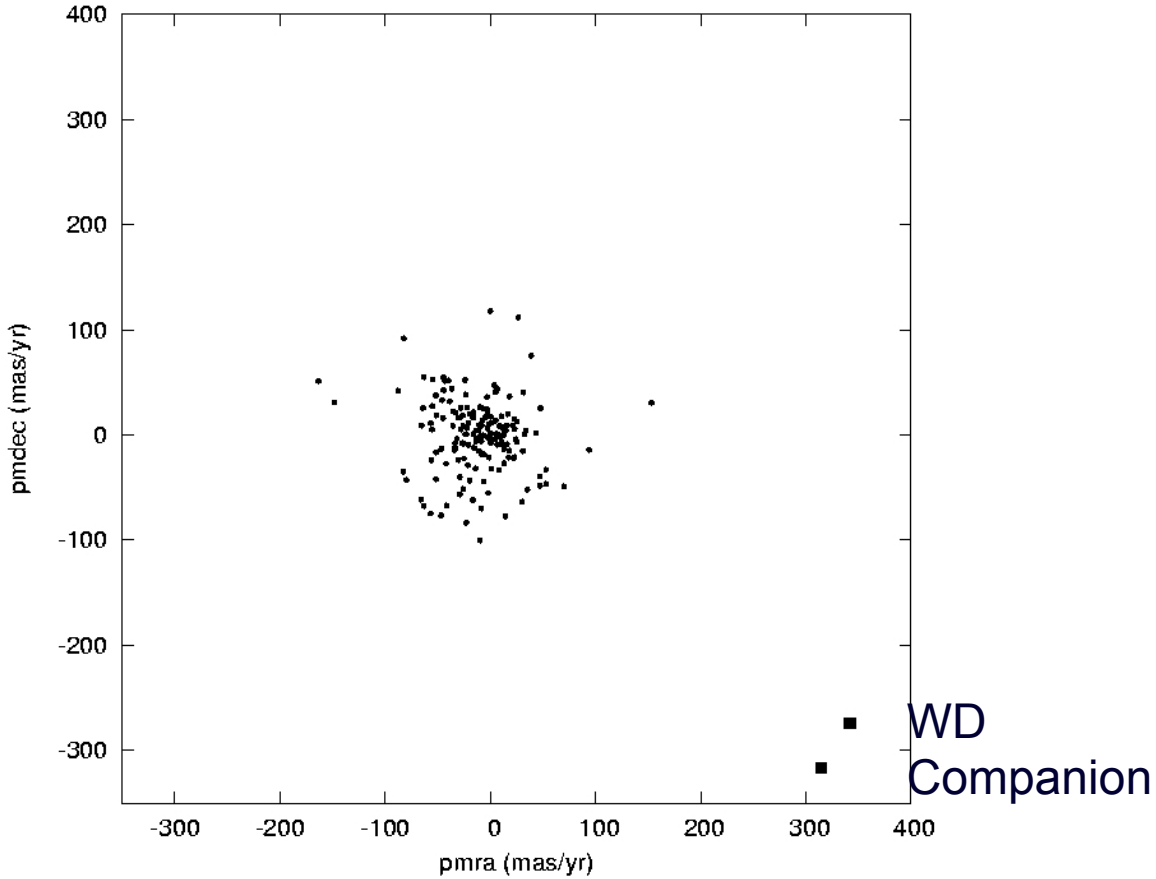
GJ3483 (LTT3059 / WD0806-661)







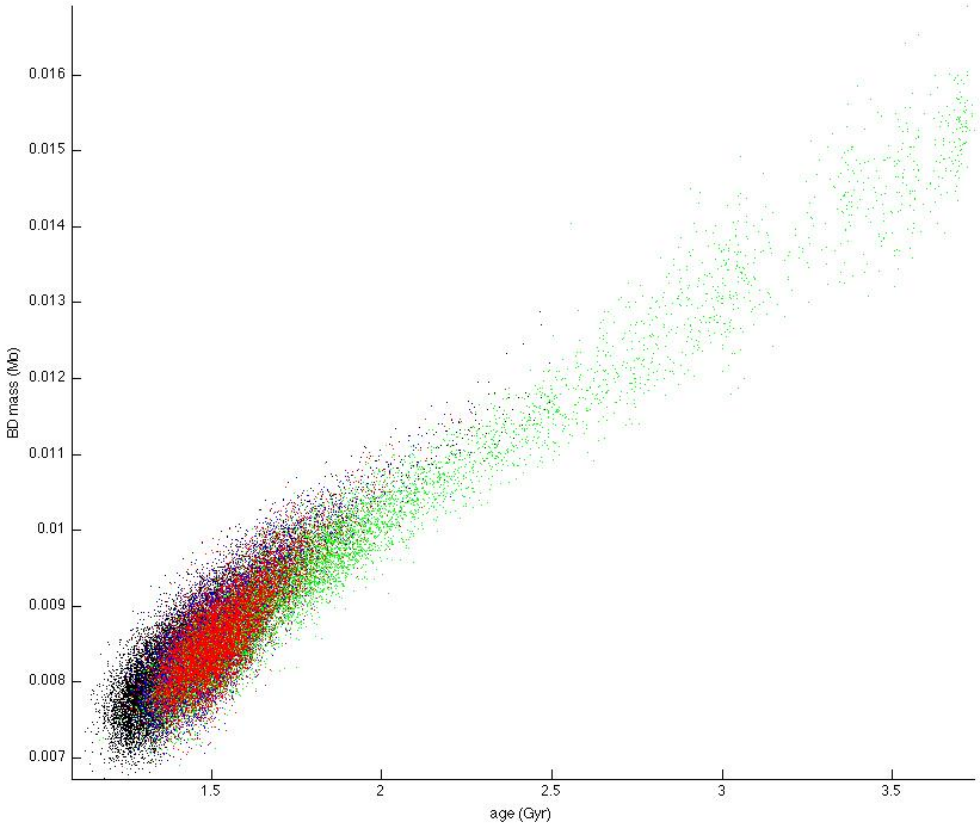
# Proper motion




- PM error +/-25mas/yr

# Candidate parameters

- WD
  - $0.58M_{sun}$,
  - Progenitor mass $1.8\text{-}2.4M_{sun}$
  - Total age 1.2-2.5Gyr
  - Distance 19.2pc
- Candidate
  - 4.5micron mag = 16.75+/-0.08
  - $6\text{-}10M_{Jup}$
  - 310-380K
- Binary
  - Projected separation 130” / 2500AU
  - Original separation 700AU

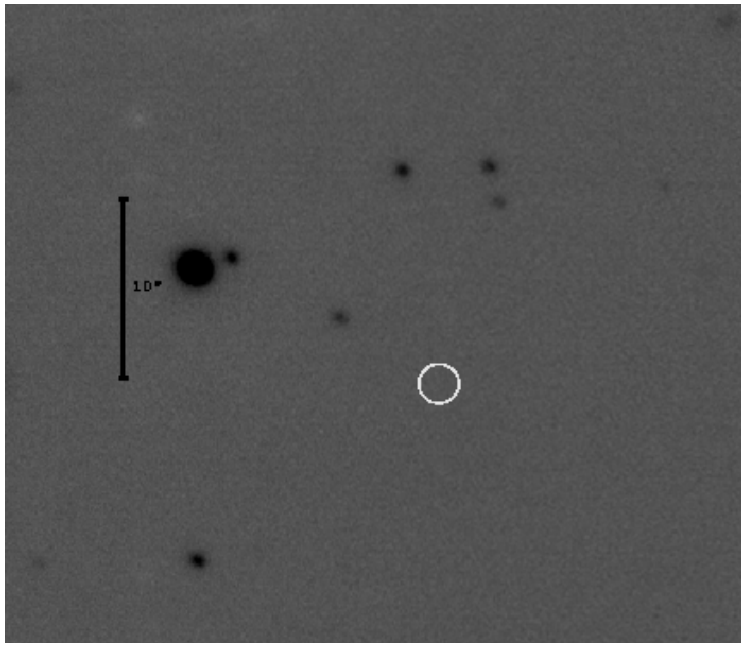

0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
BD mass (Mo)
1.5
2
2.5
3
3.5
age (Gyr)

# Candidate parameters

- WD
  - 0.58$M_{sun}$,
  - Progenitor mass 1.8-2.4$M_{sun}$
  - Total age 1.2-2.5Gyr
  - Distance 19.2pc
- Candidate
  - 4.5micron mag = 16.75+/-0.08
  - 6-10$M_{Jup}$
  - 310-380K
- Binary
  - Projected separation 130” / 2500AU
  - Original separation 700AU

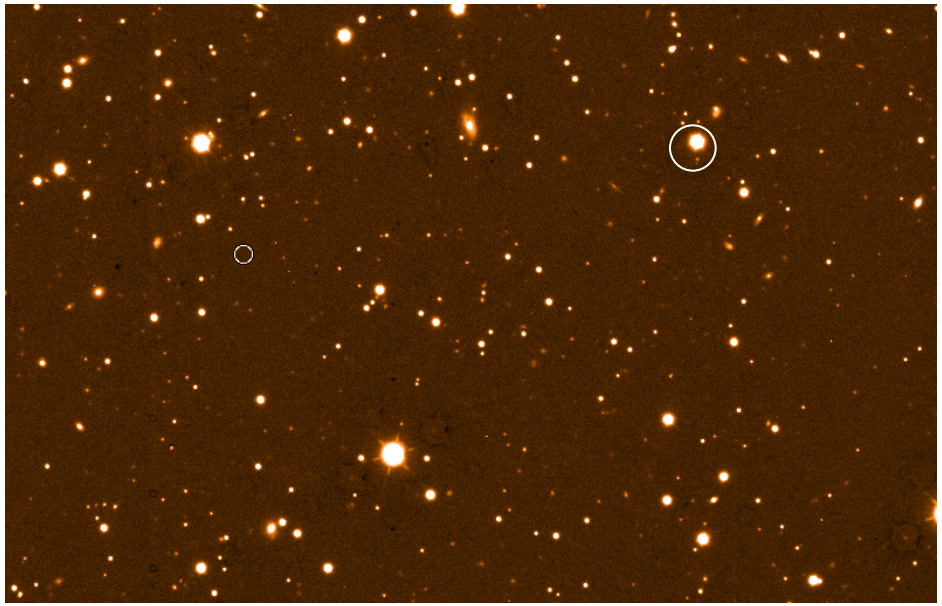
# Y band observation

- VLT Hawk-I May 2012
- No detection
- Sensitivity limit Y~22.2



# J-band observations

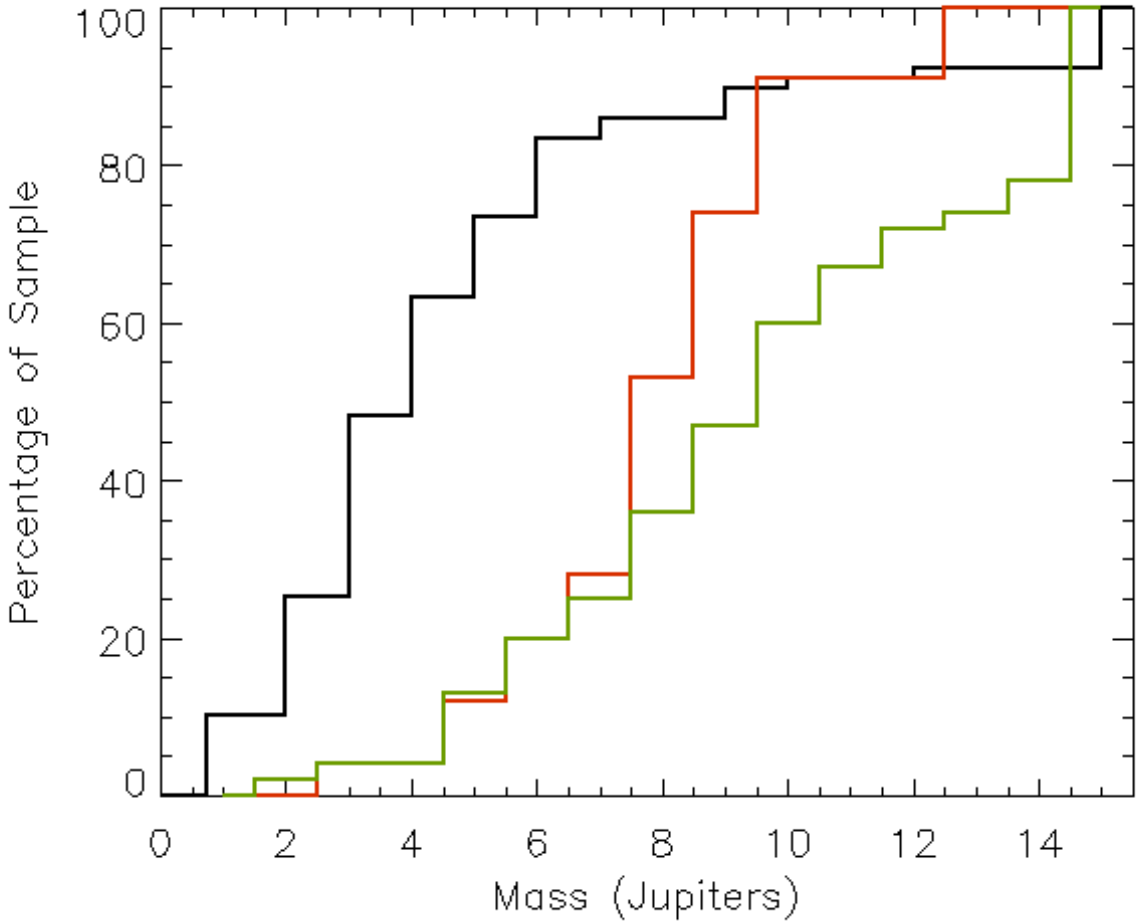
- Three hours with Magellan FourStar in March 2012
- No detection to J~23.5
  - J-[4.5] >~7
  - Redder than any known T dwarf – a Y dwarf?
  - Suggest mass 6-9$M_{Jup}$ and 310K < $T_{eff}$ < 350K
- Limiting sensitivity of field:
  - 2.5$M_{Jup}$ / 200K (COND models)
  - For unresolved companions ~10$M_{Jup}$ / 400K



# Planet or brown dwarf?

- Is GJ3483B a brown dwarf or a planet?
- Forget deuterium burning limit as the discriminator
  - can we classify by formation mechanism?
- Original *projected* separation ~700AU
  - Too large for core accretion in a disk
  - Suggests disk fragmentation -> BD
    - Rodriguez et al. 2011
- But unstable, eccentric orbits expected in end states of stellar evolution
  - Debes & Sigurdsson 2002, Villaver & Livio 2007, Veras et al. 2011
  - Disk of $2M_{sun}$ star may be massive enough to make $6M_{Jup}$ companion
  - Progenitor could be an HR8799-like system
    - A5V+$7M_{Jup}$ @68AU + $10M_{Jup}$@38AU + $10M_{Jup}$@24AU

# Spitzer survey completeness




Black: Spitzer resolved
Red: DODO resolved (Hogan et al. 2009)
Green: Spitzer unresolved (Farihi et al. 2008)

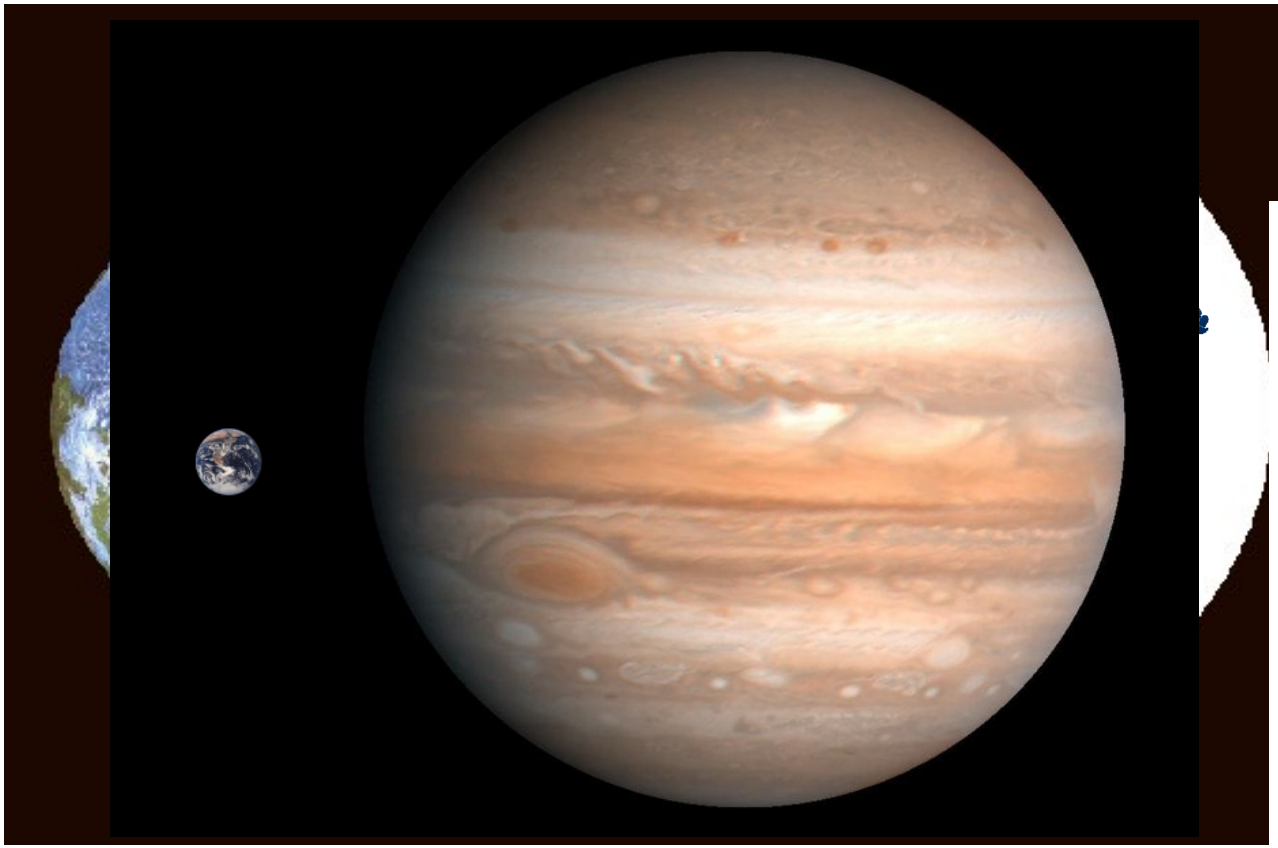
# Limits on *resolved* exoplanet companions to WDs from ground & space

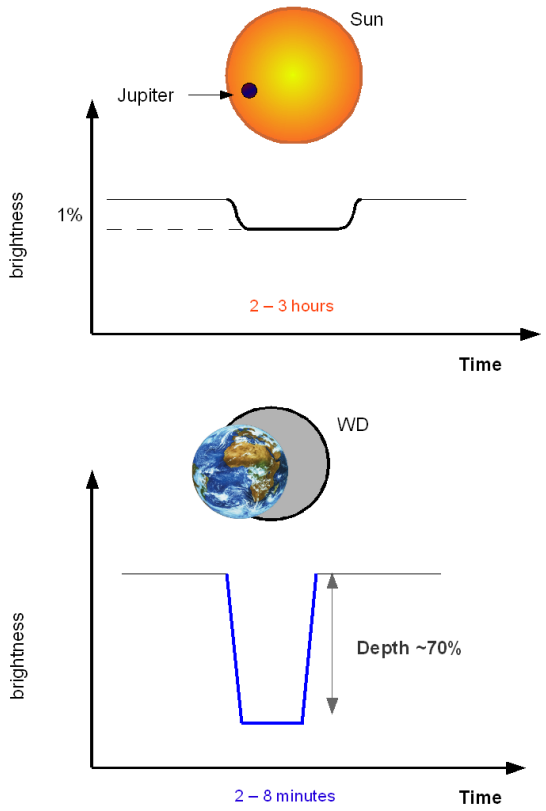
| | DODO | Spitzer |
|---|---|---|
| $>13M_{Jup}$ | <5% | ~1% |
| $>10M_{Jup}$ | <7% | 1-2% |
| $>6M_{Jup}$ | <1/3 | 1-2% |

DODO: Hogan et al. 2009, MNRAS, 396, 2074: 28 targets

UKIDSS: Steele et al. 2011, Girven et al. 2011, incidence of BDs 0.5% +/-0.3%

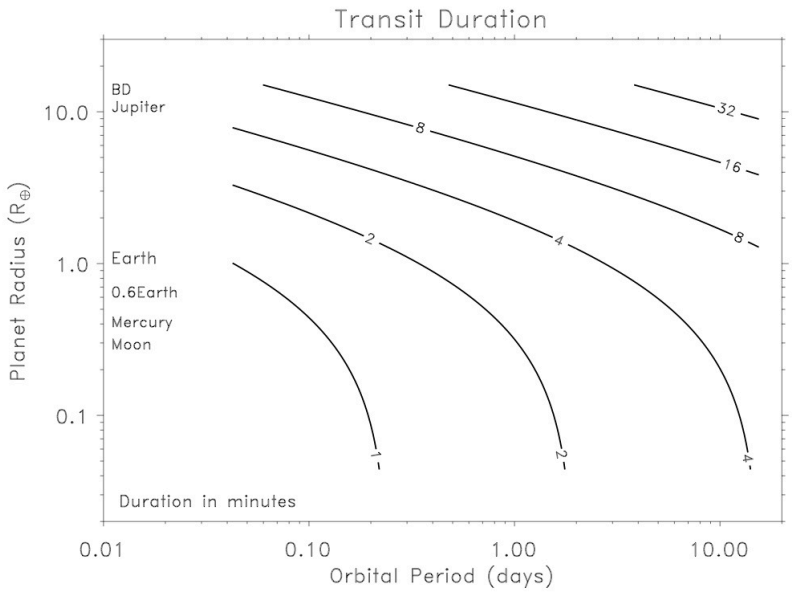
# Transits of white dwarfs

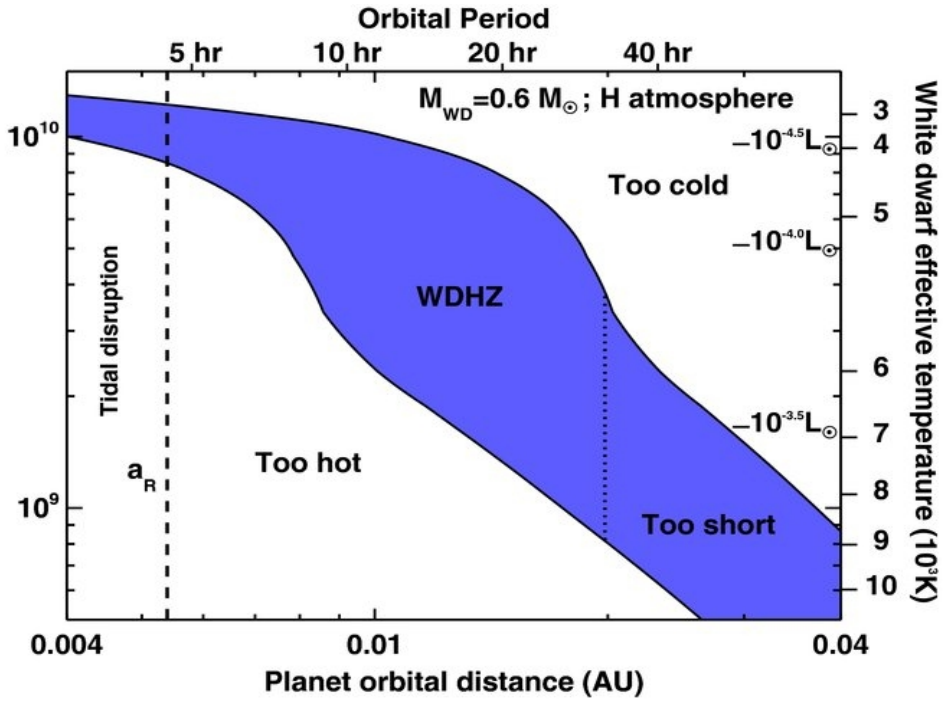




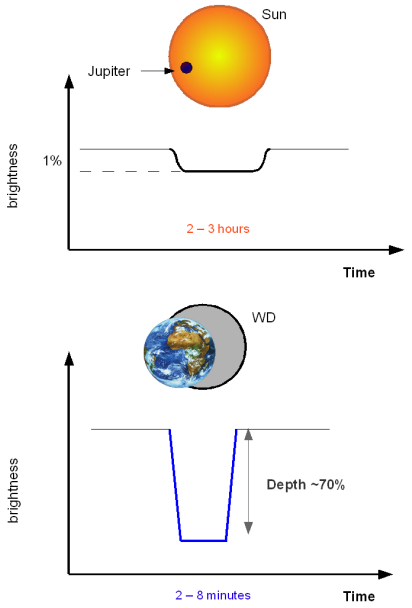

- Transit of a Jupiter: 100% or total eclipse
- Transit of an Earth: up to 100%
- Transit of Moon: ~5%
- Transit of UK: $5 \times 10^{-4}$ (0.05%)

# Transits of white dwarfs

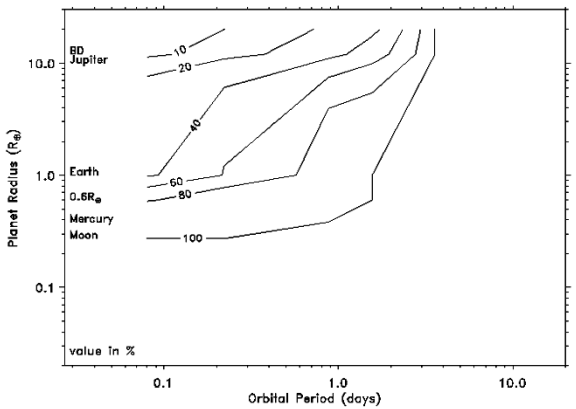


# A search for eclipsing and transiting planets with SuperWASP




- SuperWASP has observed ~300 confirmed white dwarfs since 2004
  - 1% photometry to V=13, detection limit V~15
- No eclipsing or transiting companions detected
- Limiting factors:
  - cadence: 8min for WASP v transit times of 1-few mins
  - unknown frequency of close planetary companions
    - *Survivors of common envelope evolution?*
    - *2nd generation planets?*
    - *Can rocky bodies even exist close to a WD?*
    - *Shepherd moons for dust disks?*
- Future:
  - *Wide field: (NGTS, Pan-Starrs, LSST, Plato)?*
  - *Target individual objects with 0.5-1.0m telescopes?*
  - *Kepler can detect asteroids in long period orbit*




*Faedi, West, Burleigh, Goad, & Hebb, (2011), MNRAS, 410, 899*

# Open questions, future directions


- How common are GJ3483-like objects?
  - More direct imaging searches for wide companions
  - What are their formation mechanisms?
    - Disk fragmentation?
    - Core accretion and subsequent ejection?
- Where are the perturbers that help create dust disks around white dwarfs?
  - Mid-IR photometric searches; HST, JWST, E-ELT
  - Astrometry with GAIA
- What is the lowest mass that can survive CE evolution intact to the white dwarf stage?
  - IR surveys, Transit/eclipse searches
- What is the orbital period distribution for substellar companions?
  - Are there “deserts”?
- Can rocky planets exist in close orbits to WDs?
  - Transit searches
- Can 2nd generation planets form?
  - Hot, young gas giants, metal-rich terrestrial planets?

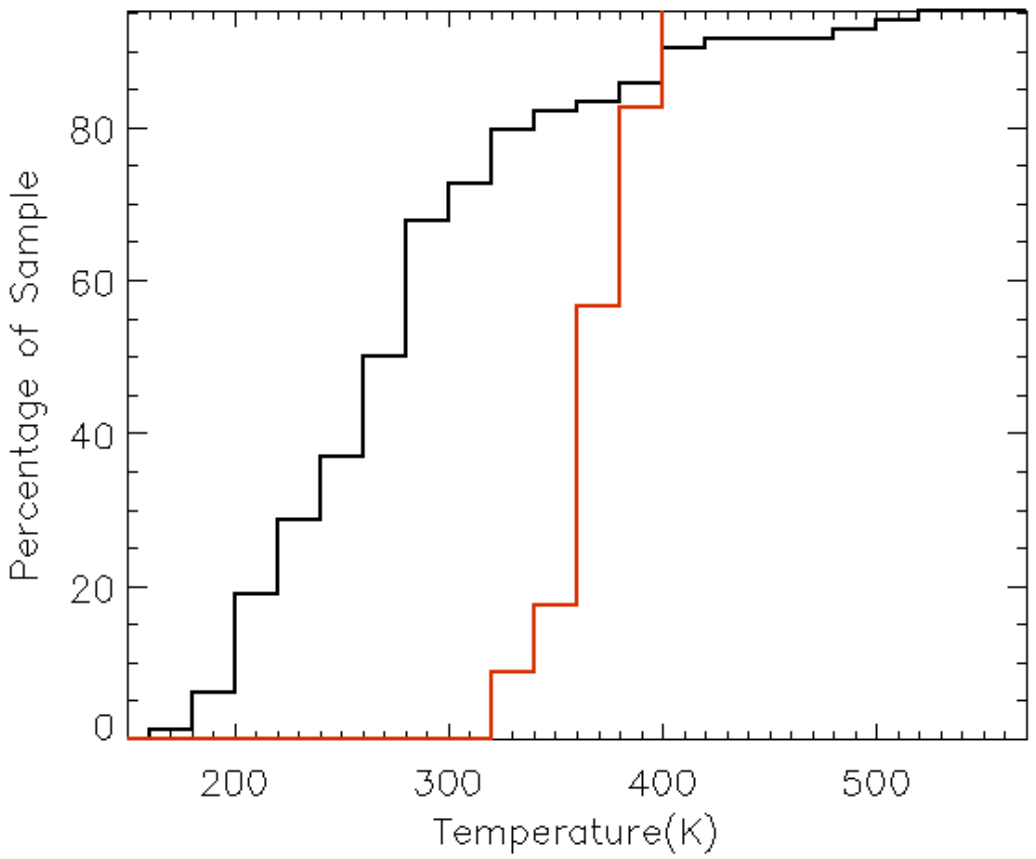
# The lowest mass companions to WDs

| Name | Mass ($M_{jup}$) | Period | a (AU) | Evolutionary status | Detection method | Comment | Reference |
|---|---|---|---|---|---|---|---|
| GD66 b | >2.4 | ~7y | >3AU | WD | Pulsation timing | Retracted | Mullally et al. 2008 |
| GJ3483 b (WD0806-661 b) | 6-9 | | 2500 | WD | Direct imaging | Y dwarf? 310K<T<350K | Burleigh et al. 2012 |
| Praesepe WD B | 25-30 | 4.2hr | 0.006 | WD, Post-CE | Radial velocity | In Praesepe open cluster | See Sarah Casewell's poster |
| WD0137-349 B | 53 | 1.93hr | 0.003 | WD, Post-CE | Radial velocity | L8 dwarf, T~1300K | Maxted et al. 2006 |
| PHL5038 B | 55 | | 55 | WD | Direct imaging | L8 dwarf, T~1400K | Steele et al. 2009 |
| GD1400 B | 60 | 9.98hr | 0.009 | WD, Post-CE | Radial velocity | L6/7 dwarf, T~1500K | Burleigh et al. 2012 |
| LSPM 1459+0857 B | 60-75 | | 26500 | WD | Direct imaging | T4.5 dwarf, T~1000K | Day-Jones et al. 2011 |
| NN Ser b<br>NN Ser c | 6.9<br>2.3 | 15.5y<br>7.7y | 5.4<br>3.4 | Pre-CV (WD+M) | Eclipse timing | | Beuermann et al. 2010 |

# Evidence for old planetary systems

1. Planets have been found by radial velocity technique around evolved giant stars
   - >3% of stars M>1.8$M_{sun}$ have planets >5$M_{Jup}$ (Lovis and Mayor 2007)
2. White dwarfs have been identified as wide companions of planet-hosting stars
   - eg CD-38 10980 (Mayor et al. 2004), eps Ret (Raghavan et al. 2006, Chauvin et al. 2006, Farihi et al. 2011)
3. Growing number of brown dwarf companions in close and wide orbits
   - WD+BD fraction >0.5+/-0.3% Steele et al. 2011, Girven et al. 2011, Debes et al. 2011
4. Metal-rich circumstellar dust and gas disks discovered around white dwarfs
   - See various papers by eg Jay Farihi & collaborators, Boris Gaensicke & friends

# Spitzer survey completeness




Black: Spitzer resolved
Red: DODO resolved
(Hogan et al. 2009)

# WD/BD binary separations